

driving gear reliability; resource of driving gear; tooth gearing durability;  
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## THE POSSIBILITIES OF IMPROVING THE OPERATIONAL CHARACTERISTICS OF VEHICLE GEAR BY THE USE OF CYLINDRICAL ARCHED TOOTH GEAR DRIVE

**Summary.** In this article, one of the most promising methods of increasing the operational characteristics of a vehicle gear by the use of cylindrical gear drives with arched teeth is presented. Despite a number of advantages, these gearings are not widely used due to design and manufacture complexity. Possible options of edge cutting machining of cylindrical gearwheel arched teeth are considered. The progressive process technology proposed by the authors combines the roughing by multi-purpose cutter head for bevel gear with circular tooth and finishing by cutter head with zero angle of cutting edge.

## ВОЗМОЖНОСТИ ПОВЫШЕНИЯ ЭКСПЛУАТАЦИОННЫХ ХАРАКТЕРИСТИК ПРИВОДОВ ТРАНСПОРТНЫХ СРЕДСТВ ЗА СЧЕТ ПРИМЕНЕНИЯ АРОЧНЫХ ЦИЛИНДРИЧЕСКИХ ЗУБЧАТЫХ ПЕРЕДАЧ

**Аннотация.** В статье представлен один из перспективных способов повышения эксплуатационных характеристик приводов транспортных средств за счет применения цилиндрических передач с арочными зубьями. Несмотря на целый ряд преимуществ, такие передачи не имеют широкого распространения это связано со сложностью их проектирования и изготовления. Рассмотрены возможные варианты лезвийной обработки арочных зубьев цилиндрических колес. Авторами предложен прогрессивный технологический процесс. Сочетающий черновую обработку универсальными резцовыми головками для обработки конических колес с круговым зубом и чистовую - резцовыми головками с нулевым углом профиля.

### 1. INTRODUCTION

On the basis of the experience of producers of automobile and locomotive plants, the basic direction of vehicle drives development is increasing carrying capacity, resource, smoothness and the quietness [1] of gearing and preservation of mass and dimensions.

Nowadays, it may be possible to partially solve these problems by using ultra-high tensile alloys and additional finishing operations as well as laying ultra high tensile and wearproof coating [2]. All

these increase the costs of the final product. That is why the new development of gear construction and the technology of its production is so necessary [3].

## **2. EXPERIENCE OF CYLINDRICAL ARCHED GEAR APPLICATION IN THE VEHICLE DRIVES**

Cylindrical involute gearings used in vehicles have several variations: straight-toothed, helical and herringbone. Each of them has its own features and range of applications. Particularly, straight-toothed gears have the capability to axial engage and disengage. Helical gears have a higher engagement factor, carrying capacity and smoothness, as compared with the straight-toothed. However, there is a disadvantage of the above-described engagement in a significant axial component of the force during the work, which places certain limits on the choice of support bearing. Herringbone gearings are characterised by a larger carrying capacity, compared to helical gears, smoothness and axial force compensation. Among other clear merits, this kind of gear still has essential disadvantages, such as considerable width of the geared ring, laboriousness and value of end item, and assembling complexity.

Application of a cylindrical arched gearing can become a new phase. On average, the noise level of the cylindrical arched gearing reduces 2 times; durability increases 2.2 times; wear resistance increases 3 times; cost increases by no more than a factor of 1.5, in comparison with analogue gearings of the same precision [4]; pitting and scoring resistance rises 1.5-2 times [5].

The relevant application of spur-gear with arched teeth domain is their use in the towline of diesel locomotives, electric locomotives and electric trains, which in most cases will be able to solve the problem of inadequate resources and high specific quantity of metal of such assemblies. Comparative analysis of locomotive gear durability with spur and arched teeth has demonstrated that in actual operating conditions the switch to a new type of engagement while keeping wheel overall dimensions allows the raising of the back-to-back endurance of transferring resource by more than twice [6].

There is an experience of replacement of helical engagement with the arched in the main gearing of Kamaz's drive axle. The fact that with the scheduled average service life, in 270 thousand kilometres about 30% of axles breakdown at the mileage of less than 150 thousand kilometres is a prerequisite for carrying out such a complex of theoretical, engineering and technological operations. In general, it is caused by the appearance of extreme axial force, which provokes straining of stay nut and outer race of the angular-contact bearing, which in turn results in its destruction and outage of driving gear. In the case of using a cylindrical arched gearing, axial force is absent; the assembly of driven cylindrical gearwheel is placed on the radial roller bearings that accept axial throw. The driven wheel then has the ability of self-aligning. Such design of the main gearing creates the prerequisites for increasing of driving axle's longevity and improving its operating characteristics. As a result of the carried out upgrade, mileage of driving axle's final drive was 450 thousand kilometres at the time of the inspection. Deterioration was within the permissible limits. Consequently, use of cylindrical gearing with arched teeth allows for simplifying the production and exploitation of the above-described assembly, increasing general resource of drive design.

## **3. PROBLEMS OF DESIGN AND MANUFACTURE OF CYLINDRICAL ARCHED GEARING**

In modern machines drives, cylindrical arched gearings are not widely used. Part of the reason for it is that there is no competitive positioning in the field of cylindrical arched teeth gearing production in the world market. The technologies used either do not allow the making of the toothed profile with the required accuracy or they are inefficient.

Perfection of the construction of cogwheel with arched teeth is important, as is prior direction of the improvement of quality and output capacity of machines and mechanisms.

Analysis of the known techniques of the geometrical computation and methods of manufacturing arched toothed gearing has demonstrated the fact that they have a common structure, but they also differ from each other by geometrical and kinematic diagrams and several parameters of operational engagement [4, 7, 8]. Besides, existing techniques have no unified approach to solving design problem of the production process and they are not interchangeable.

These facilitate its significant disadvantage: when it is required to make a choice of this or that kind of gearing and, therefore, this or that manufacturing method of cogwheel, it is essential to sequentially compute parameters of gearing on each techniques and compare the results, which lead to unwarranted expenses and do not allow quick decisions on which of the gear processing methods is efficient in a particular case.

Considering the above-stated, development of common techniques of the automated design process of cylindrical cogwheel with arched teeth production becomes a problem that is significant for vehicle manufacturing and actual for modern machine construction.

#### 4. METHODS OF CYLINDRICAL ARCHED GEARING PRODUCTION

Arched tooth in all of the sections that are perpendicular to the wheel axis has an involute profile that is situated on a curve of the loft of the cogwheel reference cylinder. A circular arc around the point located on the central longitudinal axis of base cylinder  $r_b$  loft is used as such curve. Fig. 1 shows the general view of a cylindrical arched gearing and single tooth separately.

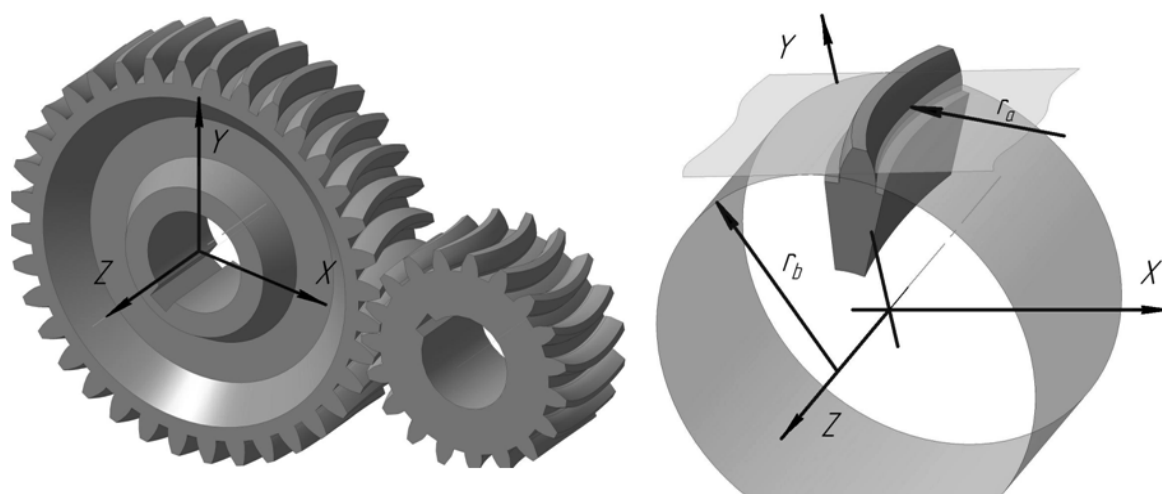


Fig. 1. Arched engagement (a – arched gearing, b – arched tooth parameters)

Рис. 1. Арочное зацепление (а – арочная зубчатая передача, б – параметры арочного зуба)

At the present time, several basic methods of cylindrical gearing arched teeth are known:

- rolling method with intermittent (fractional) indexing;
- plunge cutting method;
- rolling method with continuous indexing by using the spiral disk-shaped instrument;
- arched teeth fabrication by end milling cutter;
- arched teeth fabrication by a set of tool head with zero angle of cutting edge profile.

During arched teeth cutting by rolling method with intermittent indexing, teeth processing is performed by front gear-cutting tool head for cutting the circular-arc teeth of bevel gear [4]. In that case, a wheel with constant involute teeth profile in crown central section, which is perpendicular to the wheel axis, is threaded. But generating angle will change significantly in section differed from central (fig. 2). For such a gearing processing, cutting the paired wheel with identical generating angles in all sections and mounting of a wheel with checked axial spacing are needed [9].

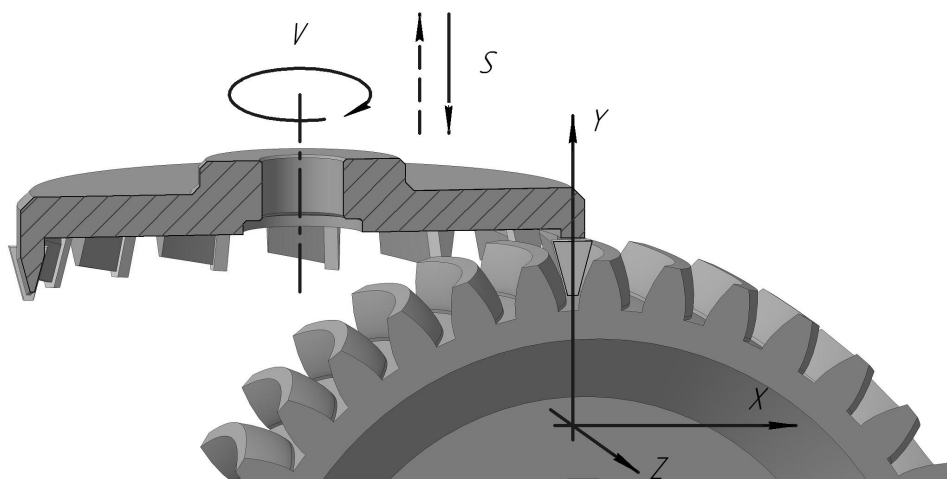


Fig. 2. Roughing arched teeth by gear-cutting tool heads

Рис. 2. Черновая обработка арочных зубьев зуборезными резцовыми головками

The plunge cutting method allows the generating of the tooth slot of one of the gearing arched wheels by radial digging of gear-cutting tool head for processing bevel gears with circular-arc teeth. This method is more efficient, but it also distorts the tooth profile in sections that differ from the central one.

Teeth cutting by the rolling method with continuous indexing determines the radius of curvature of the operating surface; teeth profile are distorted and loading irregularity along the full length is caused. That leads to the axial load appearance, increasing deterioration and quick fault of gearing [9].

Tooth profile, whose geometry corresponds to the theoretical, providing the best engagement, is obtained by treating the end milling cutter and a set of two cutter heads, one for the concave flanks and the other for the convex ones with zero angle of cutting edge profile. While processing arched tooth by end milling cutter, consecutive incremental surfacing is happening in several passes. That method permits the provision of the forming of the involute profile along the full length of the arched tooth, but also it is not very effective because of the low effectiveness and severe wear of the cutting tool.

That approach to forming an arched tooth profile by using a set of two cutter heads is not new. The first reference on this processing technology is the patent by Joseph C. O'Brien [10]. Until recent times, that processing technology did not have widespread application. A set of two cutter heads is used for the realisation of the processing technologies [rolling method with intermittent (fractional) indexing and plunge cutting method] on the gear-manufacturing machine.

The way of processing by a set of cutter heads with zero angle of cutting edge profile is remarkable for use on a universal CNC machine. The tooth profile is formed, not by the lines of the cutting edges as during the rolling method, but by the top point of the cutter.

Application of the processing option by a set of two cutter heads with zero angle of cutting edge profile for serial processing convex and concave operational surfaces of tooth slot is the most technological. Moreover, with the help of this method, finishing forming of heat-treated teeth with the hardness till HRC 60 can be conducted.

At wheel processing of average and coarse pitch by this method, the problem of the roughing occurs, as during radial bite of the slot by tool head with zero angle of cutting edge profile the large volume of metal still remains. This metal has to be deleted by additional passes till the moment of attainment of the surface of the finishing allowance, which will increase the operation's laboriousness, and, as a consequence, the final production cost.

A combination of roughing and finishing methods with different structures of cutting and tools is a promising direction of productivity improvement of cylindrical wheel arched teeth processing [11]. Thus, it is good to use a gear-shaping cutter head for a bevel gear with circle-arc teeth by the rolling method, radial infeed or a combination of both methods for roughing. The forming method of the operational surface by cutter head with zero angle of cutting tooth profile is applying for finishing.

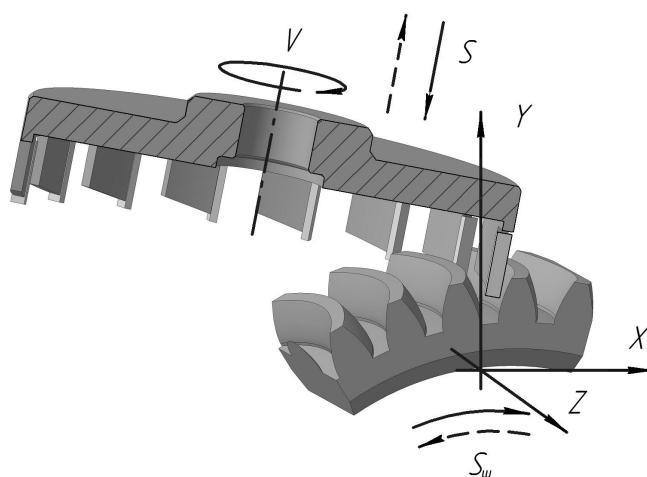


Fig. 3. Finishing scheme of the cylindrical arched wheel by gear-cutting tool head with zero angle of cutting edge profile

Рис. 3. Схема чистовой обработки венца цилиндрического арочного колеса зуборезной резцовой головкой с нулевым углом профиля

Such a combination of two processing methods makes it possible to increase productivity by eliminating the greatest amount of metal while roughing and to achieve the desired accuracy while finishing. Besides, roughing is carried out by standardised tools and can be useful on universal milling machines in case of special attachments, which reduces gearing cost.

The efficiency of forming a complete cycle of arched gearwheel by cutter head with zero profile angle is comparable with the production efficiency of a straight-toothed and helical wheel in the absence of heat treatment and follow-on finishing operation. In that case the processing time of an arched gearwheel with the number of teeth equal to  $z=18$  and module  $m=8$  mm is about 20 minutes [4].

## 5. CONCLUSION

1. Application of cylindrical arched tooth in high-loaded transfer drive allows increasing output capacity, raising driving gear durability and motion smoothness and reducing mass/volume indicators as well. Lack of axial load will lead to the simplification of assembly design on the whole. Increased drive resource of given type will reduce repair costs.
2. Generalised methodology development of automated process design of cylindrical cogwheel with arched teeth production is significant for the vehicle production and actual for modern machine-building.
3. A combination of methods of the roughing by cutter head for bevel gear with circular teeth and finishing by cutter head with zero angle of cutting edge is the most rational scheme of the cylindrical arched wheel processing, which allows for achieving the desired accuracy in combination with high productivity.

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